Patient-specific virtual insertion of electrode array for electrical simulation of cochlear implants

Nerea Mangado, Nicolas Duchateau, Mario Ceresa, Hans Martin Kjer, Sergio Vera, Pavel Mistrik, Javier Herrero, Miguel Angel Gonzalez Ballester

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Patient-Specific Virtual Insertion Of Electrode Array For Electrical Simulations Of Cochlear Implants

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Nerea Mangado[1], Nicolas Duchateau[2], Mario Ceresa[1], Hans Martin Kjer[3], Sergio Vera[4], Pavel Mistrik [5], Javier Herrero[4], Miguel ángel González Ballester[6]

1. Simbiosys group, DTIC, Universitat Pompeu Fabra, Barcelona, Spain
2. Asclepios research Project, INRIA Sophia Antipolis, Nice, France
3. Technical University of Denmark, Nicecopenhagen, Denmark
4. Alma Medical Systems, Barcelona, Spain
5. MED-EL, Innsbruck, Austria
6. ICREA, Barcelona, Spain

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Purpose: Sensorineural hearing loss is becoming one the most common reasons of disability. Worldwide 278 million people (around 25% of people above 45 years) suffer from moderate to several hearing disorders. Cochlear implantation (CI) enables to convert sound to an electrical signal that directly stimulates the auditory nerves via the electrode array surgically placed. However, this technique is intrinsically patient-dependent and its range of outcomes is very broad. A major source of outcome variability resides in the electrode array insertion. It has been reported to be one of the most important steps in cochlear implant surgery [1].
In this context, we propose a method for patient-specific virtual electrode insertion further used into a finite element electrical simulation, and consequently improving the planning of the surgical implantation[2]. The anatomical parameters involved in the electrode insertion such as the curvature and the number of turns of the cochlea, make virtual insertion highly challenging. Moreover, the influence of the insertion parameters and the use of different manufactured electrode arrays increase the range of scenarios to be considered for the implantation of a given patient. To this end, the method we propose is fast, easily parameterizable and applicable to a wide range of anatomies and insertion configurations. Our method is novel for targeting automatic virtual electrode insertion. Also, it combines high-resolution imaging techniques and clinical data to be further used into a finite element study and predict implantation outcomes in humans.

Methods: The electrode array to be inserted was based on Med-EL Flex28 design. A statistical shape model was used to generate cochlear geometries [3] and their corresponding centerline, which served as input for the virtual electrode array insertion. The statistical model used real cochlea geometries obtained from a high-resolution Scanco µCT 100 system (Scanco Medical AG, Switzerland) by means of semiautomatic image processing and advanced registration techniques [4]. The cochlear centerline was located at the center of the scala tympani, under the basilar membrane. A logarithmic spiral algorithm was used in the apical region of the cochlea to extend the centerline from the statistical shape model and ensure that it actually reached the apex, region of high interest to observe the electrical nerve stimulation. Kernel ridge regression with an exact matching formulation was used to control the sampling of the centerline.
The insertion algorithm reorients the electrode array so that its centerline matches the cochlear centerline. It includes a local parameterization of both centerlines according to the parallel transport frame [4]. This has the advantage of being robust to the changes in curvature along the turns of the cochlea, in comparison with more classical parameterizations such as the tangent-normal-binormal frame. Our algorithm also allows controlling the initial roll angle, the torsion along the centerline, and the percentage of insertion from full to partial, of relevance to adapt the surgery to the real patient condition.

Results: The method was tested on 8 instances obtained randomly from the statistical shape model. The length of their respective cochlear centerlines was 26.18 ± 0.90 mm. Insertions with 0°, 45° and 90° initial roll angles were tested. The percentage of insertion from full to partial was tested within a range of 50% to 100%. The virtual insertion algorithm took less than 0.6 seconds for each simulated insertion.
In all scenarios, the obtained results were robust towards differences in anatomies. Figure 1 illustrates the parametrization of a given cochlea according to the parallel transport frame, and the array insertion that is achieved accordingly. Figure 2 complements it by quantifying the local deformation of the electrode array mesh.

Conclusions: We presented an easily parameterizable algorithm for the virtual insertion electrode arrays in a wide range of geometries and insertion scenarios. The method showed to be fast in all cases. Such virtual insertions will enable in-silico testing of the effects of a given electrode array design and positioning on the real anatomy of a given patient, through electrical simulations, and therefore improve the planning of the surgical procedure. The technique looks promising to provide clinicians and CI manufacturers with a detailed and patient-specific evaluation of factors conditioning the outcome of the whole surgical procedure.

Acknowledgement
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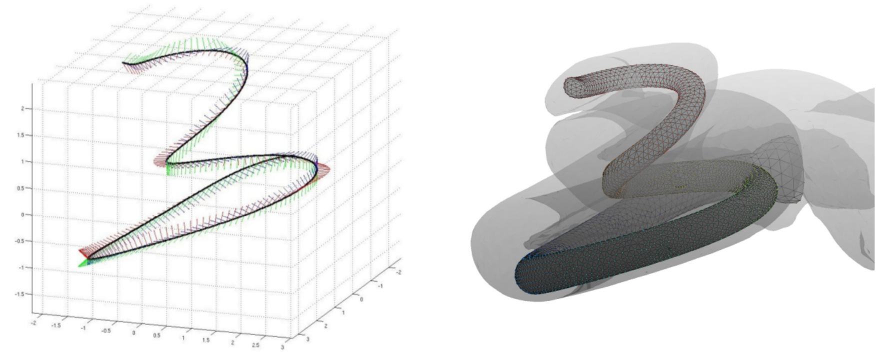

Figure1. Virtual insertion. Left: vectors representing the parallel transport frame (orthogonal basis) along the entire cochlea centerline. Right: output of the virtual insertion of the electrode mesh array into this cochlea.

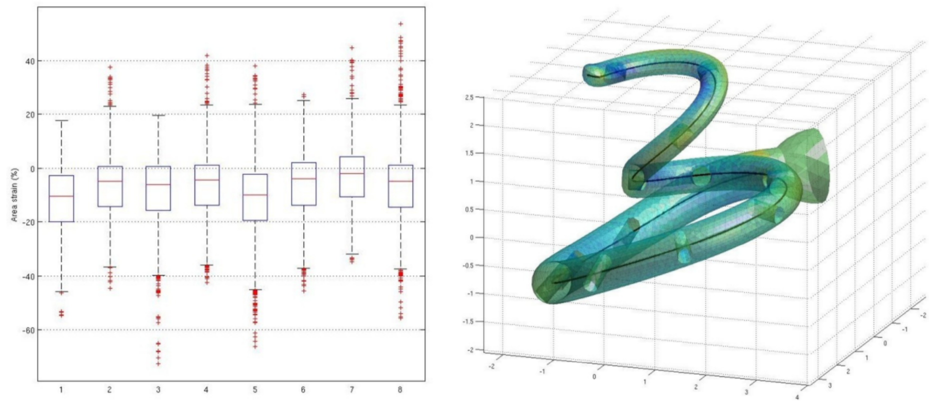

Figure 2. Quantification of the local changes in the array geometry. Left: local array deformation (area strain in %) for each virtually implanted subject: boxplot over the whole set of mesh triangles. Right: Local array deformation for the subject represented in Fig.1